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O'Connor et al.

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(54) **NODE FAILURE DETECTION FOR DISTRIBUTED LINEAR PROTECTION**

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(51) **Int. Cl.**

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H04J 1/16	(2006.01)
H04J 3/14	(2006.01)
H04L 12/24	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 41/0663*** (2013.01)

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USPC 370/328, 311

See application file for complete search history.

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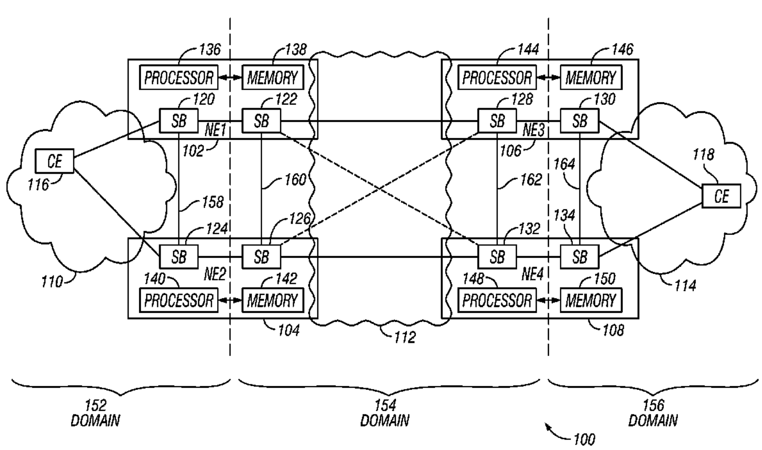
(57) **ABSTRACT**

A system includes a network element communicatively coupled to another network element through an intraportal link forming a node portal. The network element is communicatively coupled to a source network element within a network attached to the node portal. The network element is configured to monitor a protect path for an automatic protection switching ("APS") message from the source network element, determine that the APS message has been received, monitor an intraportal link for an expected message from the other network element, determine that the expected message has not been received, monitor integrity of the intraportal link, determine that the intraportal link has failed and determine that the other network element has failed based upon determining that that the APS message has been received, that the expected message has not been received, and that the intraportal link has failed.

26 Claims, 12 Drawing Sheets



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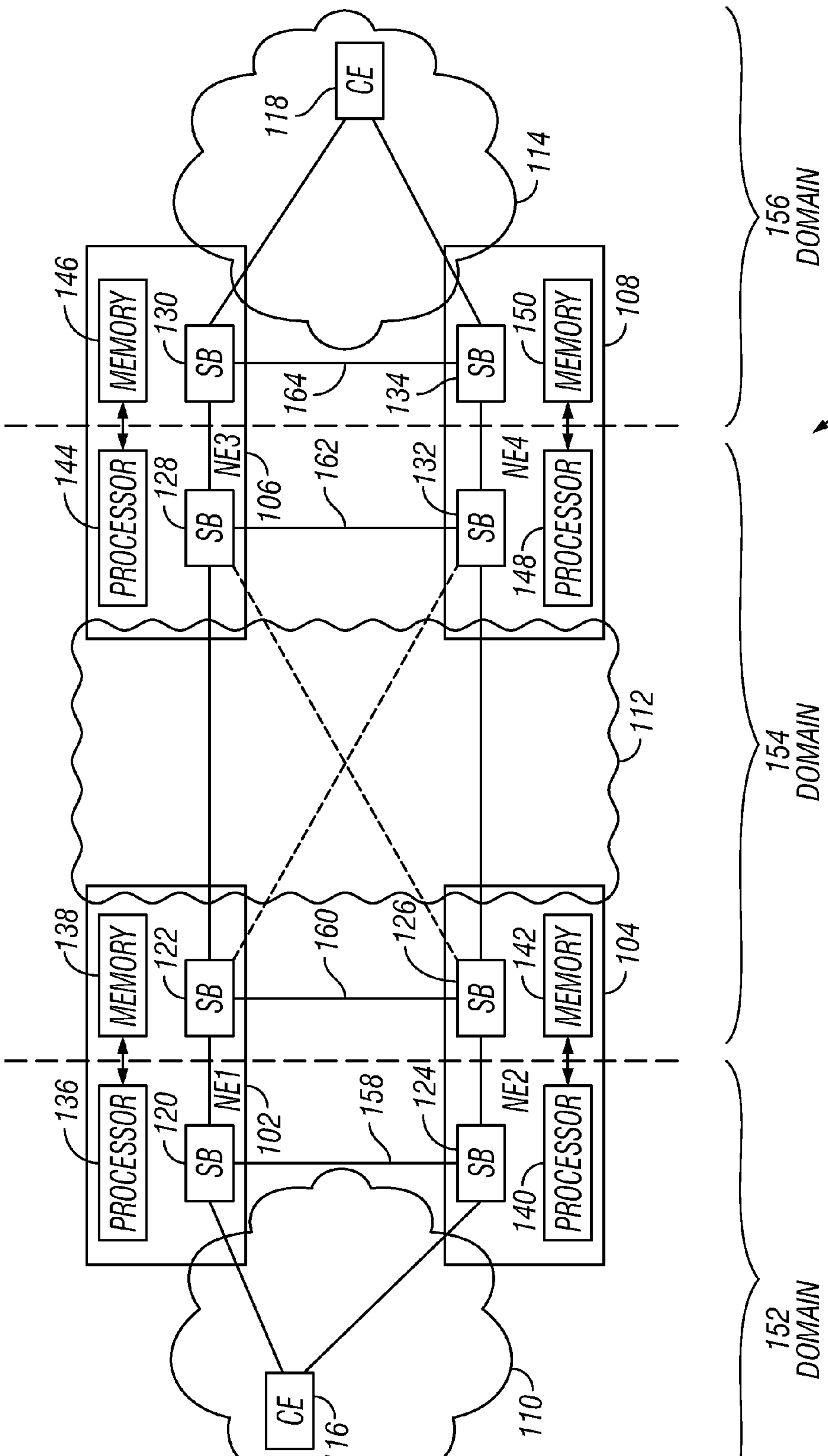
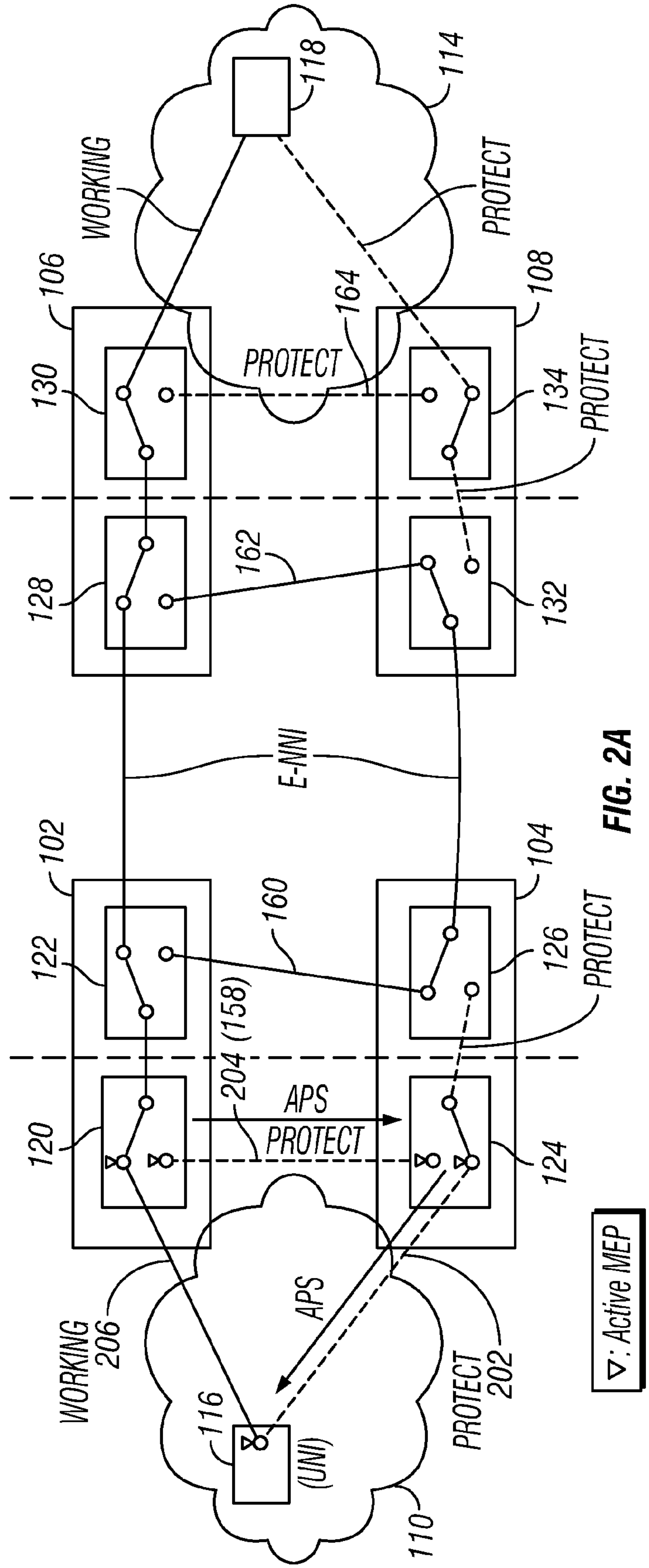

CE
118
114
146
MEMORY
130
SB
150
MEMORY
108
SB
164
134
100
144
PROCESSOR
128
SB
NE3
106
162
132
SB
NE4
148
PROCESSOR
112
138
MEMORY
122
SB
160
126
SB
142
MEMORY
104
136
PROCESSOR
120
SB
NE1
102
158
124
SB
NE2
140
PROCESSOR
CE
116
110
156
DOMAIN
154
DOMAIN
152
DOMAIN

FIG. 1



118
114
WORKING
PROTECT
106
108
164
PROTECT
130
134
PROTECT
128
162
132
E-NNI
102
104
122
160
126
PROTECT
204 (158)
APS
PROTECT
120
124
WORKING
206
APS
PROTECT
202
116
(UNI)
110
▽: Active MEP

FIG. 2A

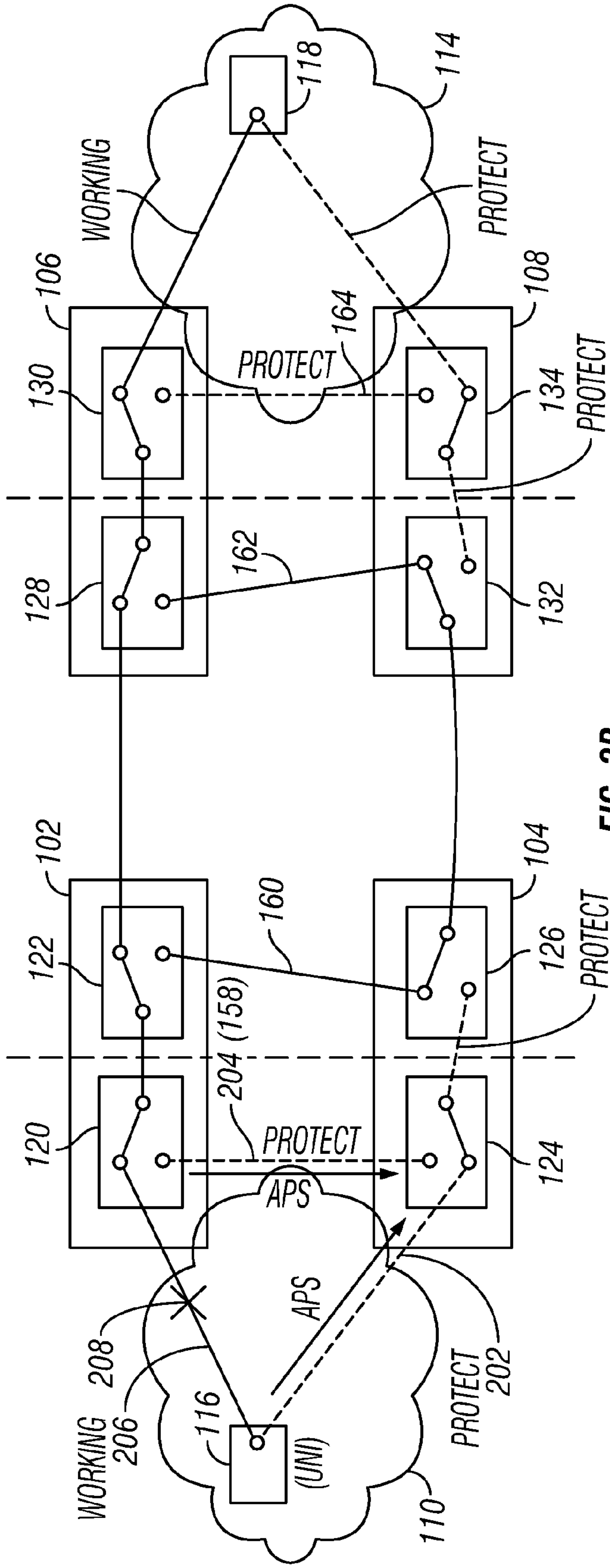
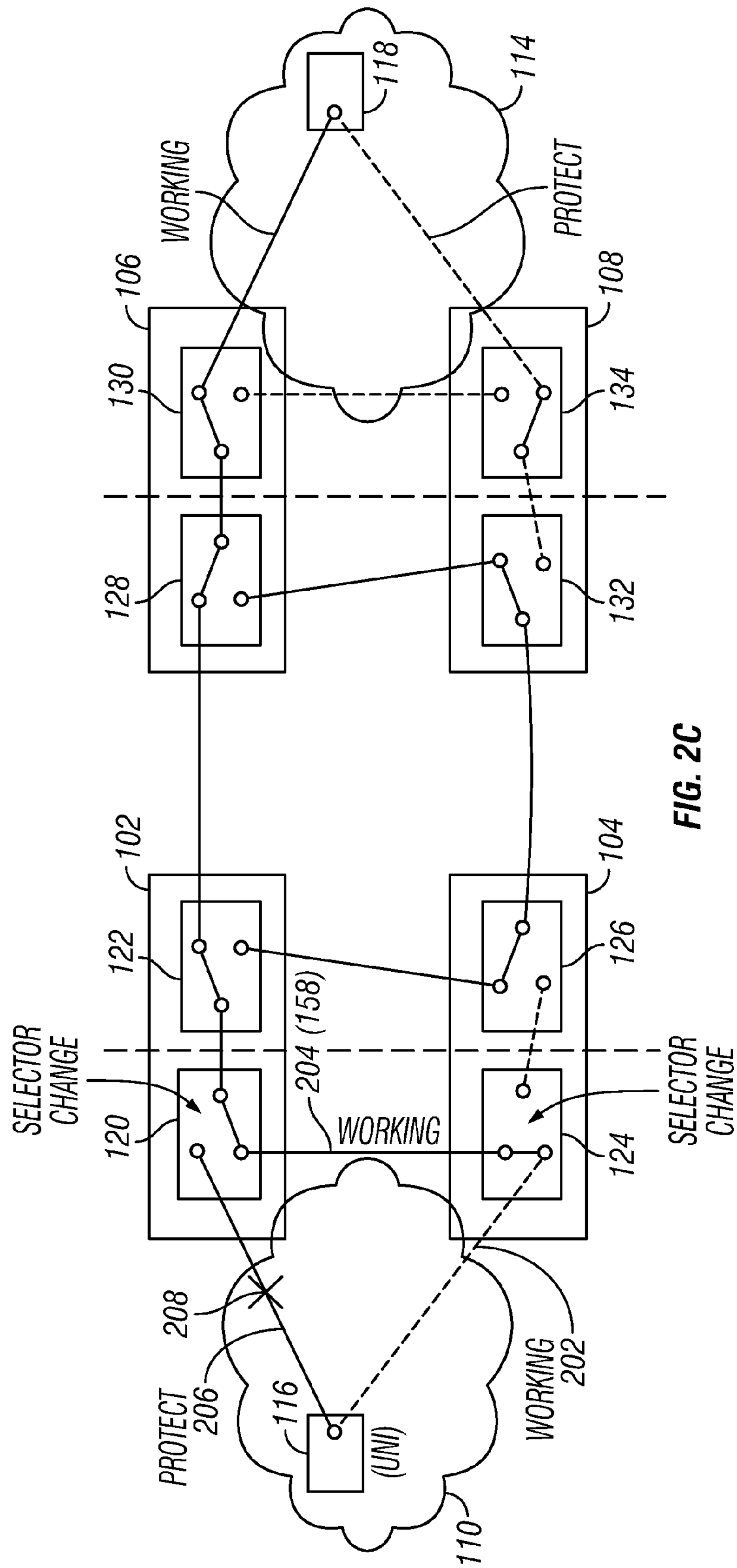
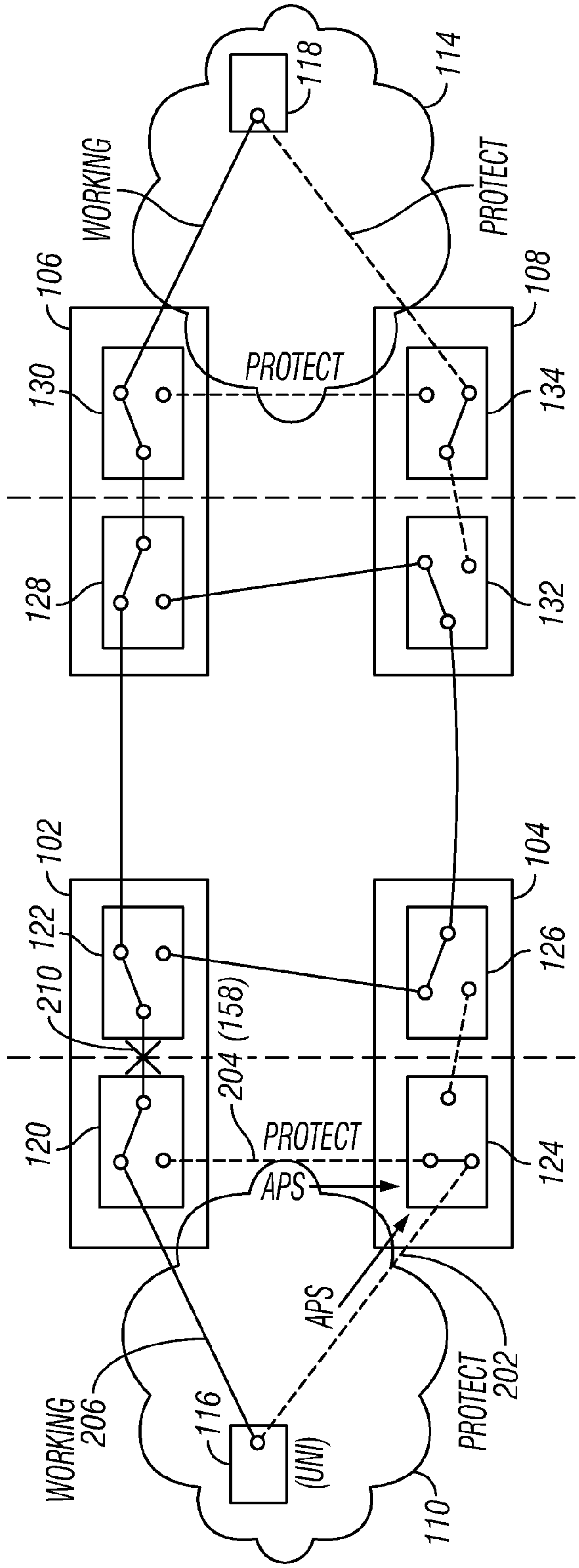

118
114
WORKING
PROTECT
106
108
164
PROTECT
130
134
PROTECT
162
128
132
102
104
160
122
126
PROTECT
204 (158)
PROTECT
120
124
APS
APS
208
WORKING
206
116
(UNI)
PROTECT
202
110

FIG. 2B



118
114
WORKING
PROTECT
106
108
130
134
128
132
102
104
122
126
SELECTOR CHANGE
204 (158)
SELECTOR CHANGE
120
WORKING
124
208
PROTECT 206
116
(UNI)
WORKING 202
110

FIG. 2C



114
118
WORKING
PROTECT
106
108
130
134
PROTECT
128
132
102
104
122
126
210
204 (158)
120
124
PROTECT
APS
APS
116
(UNI)
WORKING
206
PROTECT
202
110

FIG. 2D

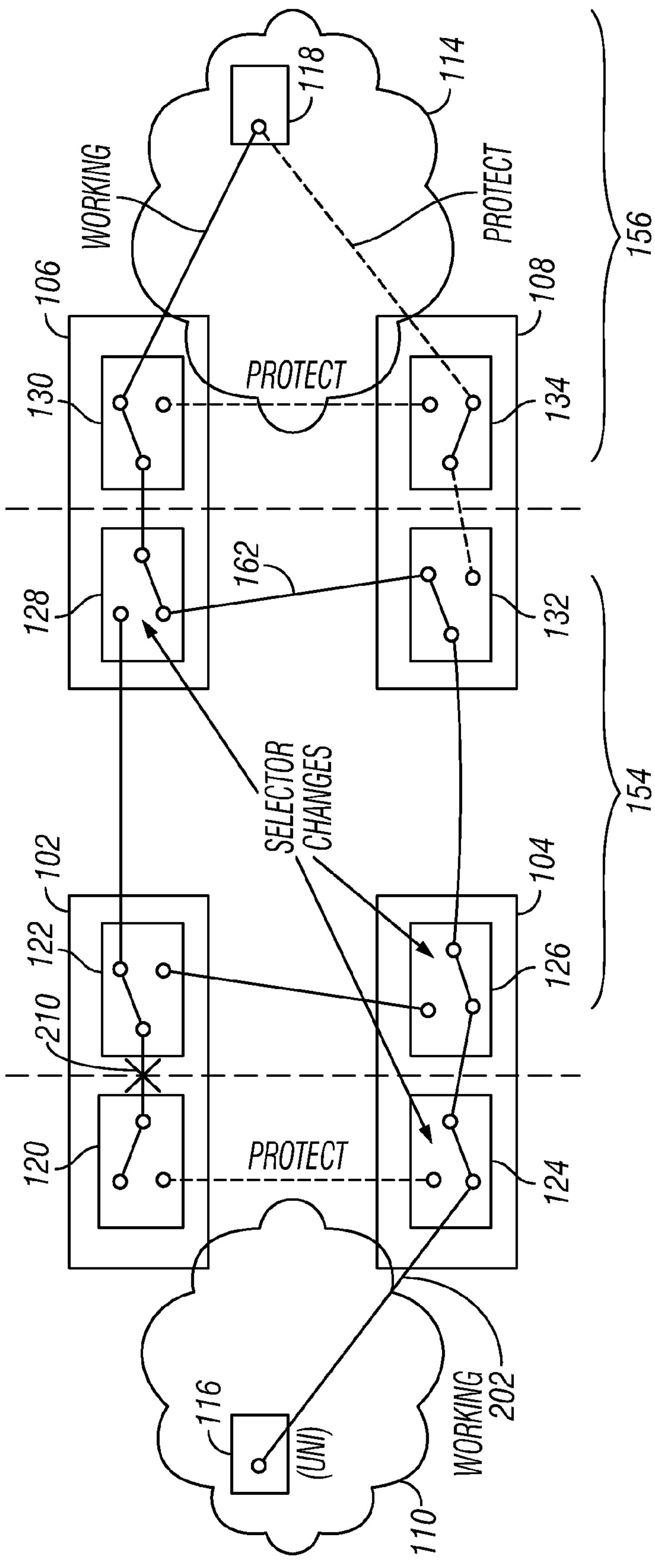
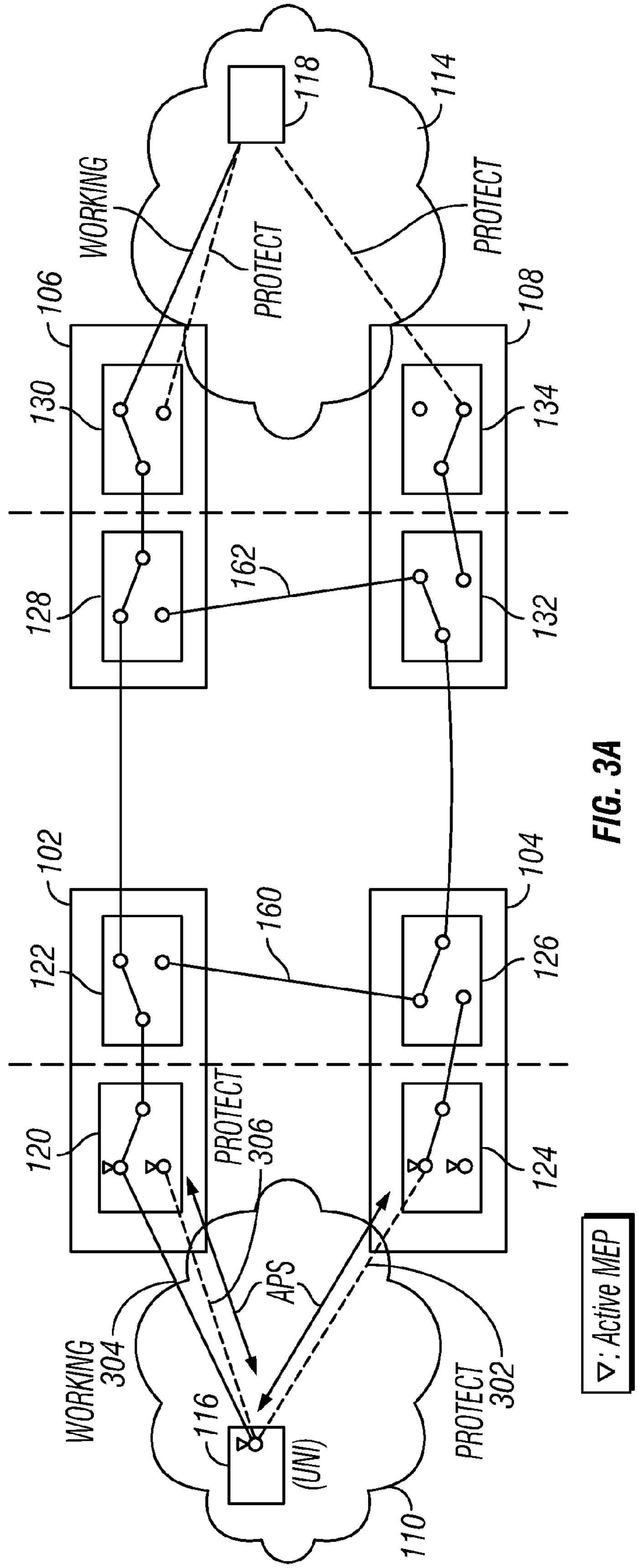

118
114
WORKING
PROTECT
106
108
156
130
PROTECT
134
128
162
132
SELECTOR
CHANGES
154
102
104
122
126
210
120
PROTECT
124
116
(UNI)
WORKING
202
110

FIG. 2E



118
114
WORKING
PROTECT
PROTECT
106
108
130
134
128
162
132
102
104
122
160
126
120
124
PROTECT
306
APS
WORKING
304
PROTECT
302
116
(UNI)
110
▽: Active MEP

FIG. 3A

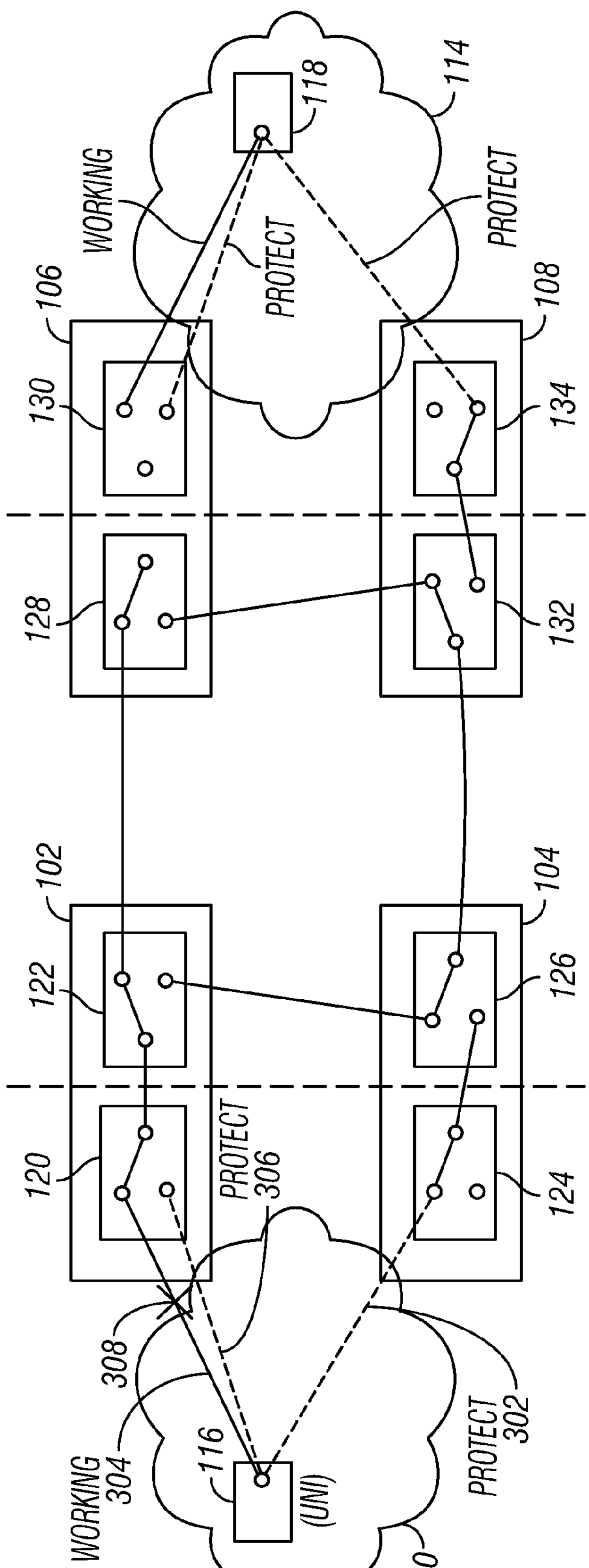

118
114
WORKING
PROTECT
PROTECT
106
108
130
134
128
132
102
104
122
126
120
124
PROTECT 306
308
WORKING 304
116
(UNI)
PROTECT 302
110

FIG. 3B

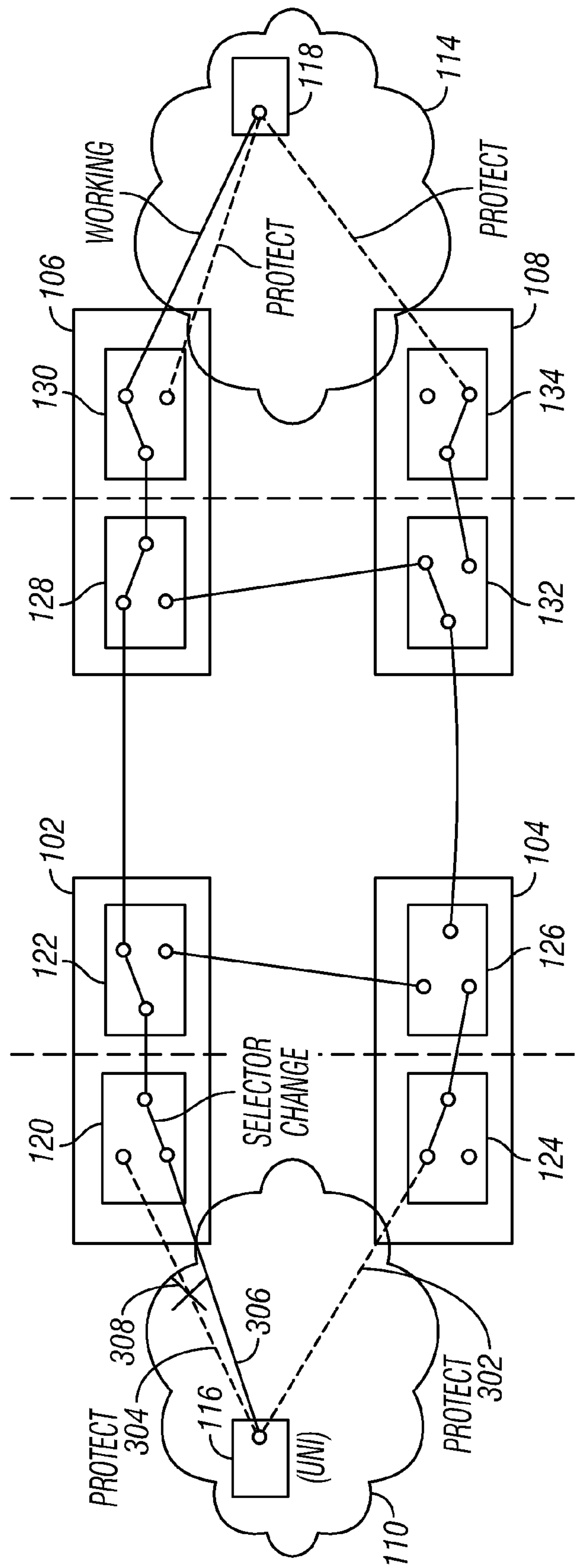
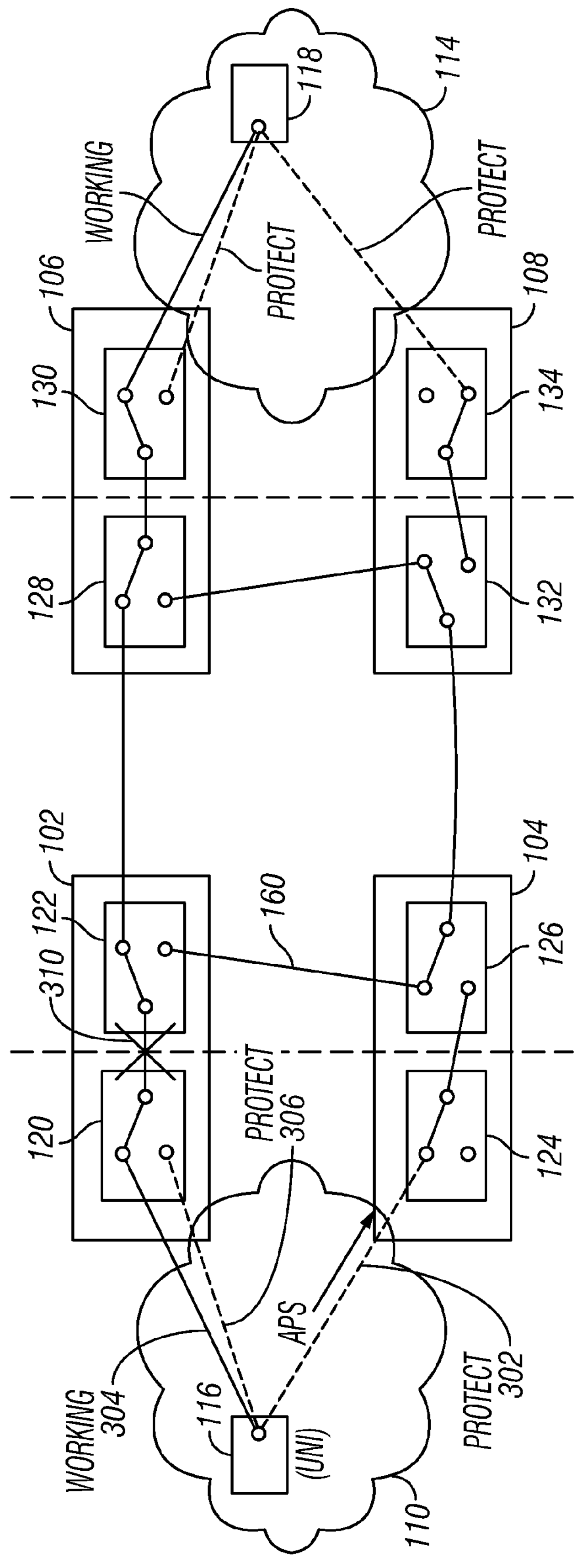

114
118
WORKING
PROTECT
PROTECT
106
108
130
134
128
132
102
104
122
126
120
124
SELECTOR CHANGE
308
306
PROTECT 304
116
(UNI)
PROTECT 302
110

FIG. 3C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114
WORKING
PROTECT
PROTECT
106
108
130
134
128
132
102
104
160
310
122
126
120
124
PROTECT
306
APS
WORKING
304
116
(UNI)
PROTECT
302
110

FIG. 3D

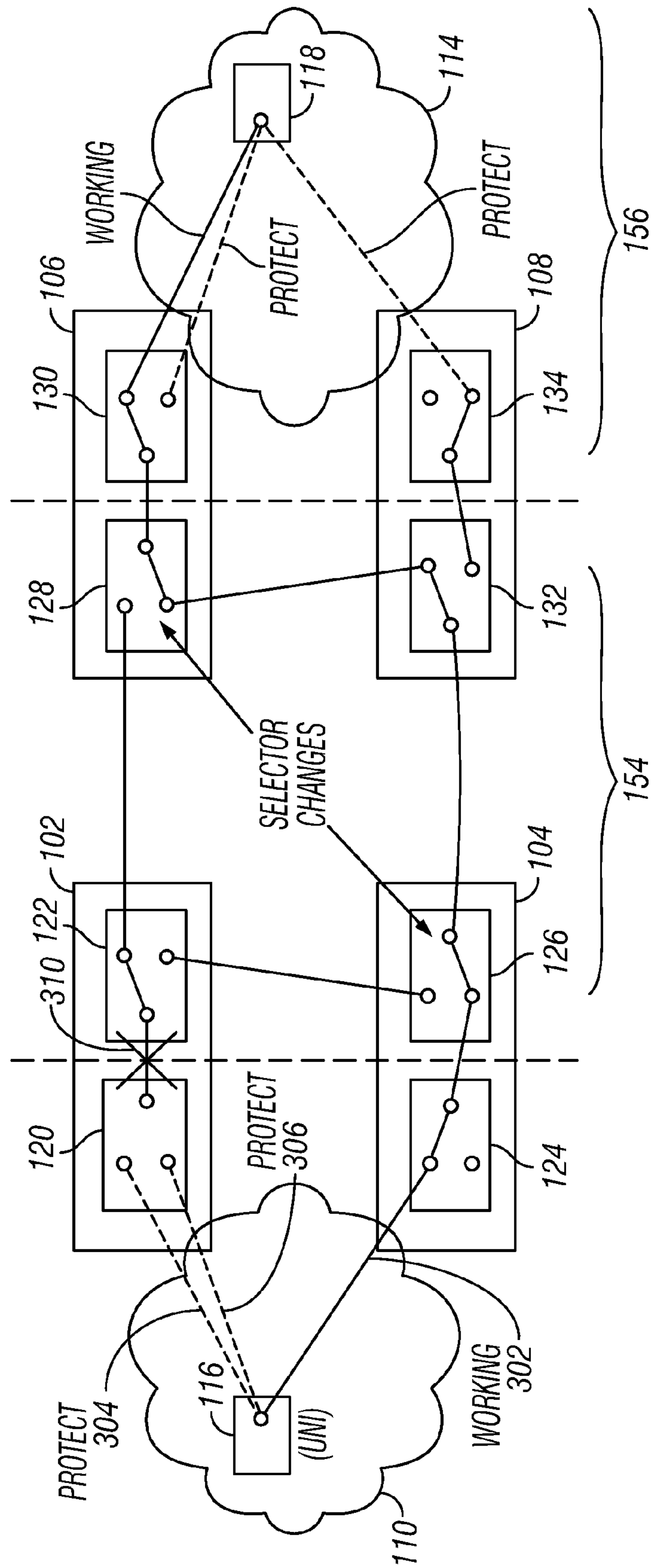
118
114
WORKING
PROTECT
PROTECT
106
108
130
134
156
128
132
SELECTOR CHANGES
154
102
104
310
122
126
120
124
PROTECT 306
PROTECT 304
116
(UNI)
WORKING 302
110

FIG. 3E

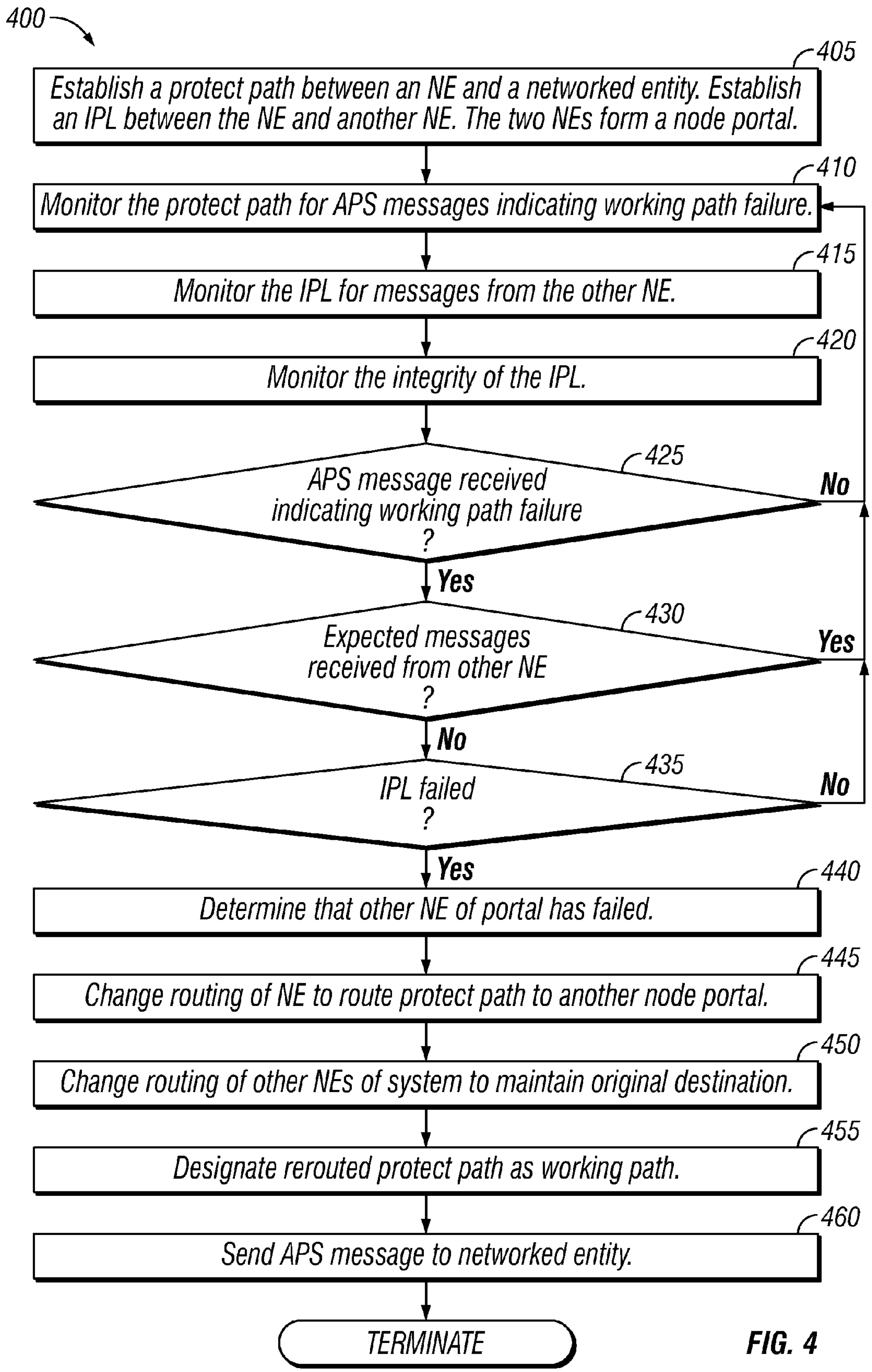
400
405
Establish a protect path between an NE and a networked entity. Establish an IPL between the NE and another NE. The two NEs form a node portal.
410
Monitor the protect path for APS messages indicating working path failure.
415
Monitor the IPL for messages from the other NE.
420
Monitor the integrity of the IPL.
425
APS message received indicating working path failure ?
No
Yes
430
Expected messages received from other NE ?
Yes
No
435
IPL failed ?
No
Yes
440
Determine that other NE of portal has failed.
445
Change routing of NE to route protect path to another node portal.
450
Change routing of other NEs of system to maintain original destination.
455
Designate rerouted protect path as working path.
460
Send APS message to networked entity.
TERMINATE

FIG. 4

NODE FAILURE DETECTION FOR DISTRIBUTED LINEAR PROTECTION

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to networked communications and, more particularly, to node failure detection for distributed linear protection.

BACKGROUND

Ethernet, Optical Transport Network (OTN), and Multi-protocol Label Switching Transport Profile (MPLS-TP) automatic protection switching under linear protection standards—such as the G.8031 Ethernet Linear Protection, G.873.1 OTN Linear Protection, or MPLS-TP Linear Protection G.8131.1 and G.8131.2 standards—may use protected paths, such as a working path and a protect path, to communicate between virtual local area networks. The paths are monitored, and if one of the paths is detected as faulty, the backup path may take over and traffic continues to flow. The standards have heretofore dictated the specific protocol for switching traffic between the paths in a variety of circumstances.

SUMMARY

In one embodiment, a method for linear protection is for a network element communicatively coupled to another network element, wherein the network element and the other network element are included in a node portal located at the edge of an administrative network domain. The method includes monitoring a protect path for an automatic protection switching ("APS") message from a source network element within a network attached to the node portal indicating a failure of a working path, determining that the APS message has been received, monitoring an intraportal link for an expected message from the other network element, determining that the expected message has not been received, monitoring integrity of the intraportal link, determining that the intraportal link has failed, and determining that the other network element has failed based upon determining that that the APS message has been received, that the expected message has not been received, and that the intraportal link has failed. The working path is between the other network element and the source network element.

In another embodiment, a method for linear protection includes determining, at a node portal, a failure in another node portal and changing a switch position of a selector function in the node portal in response to determining the failure in the other node portal. The node portal is communicatively coupled to the other node portal across an administrative network domain. Changing the switch position includes maintaining communication over a working path between the first node portal with a network element in a network attached to the first node portal.

In yet another embodiment, an article of manufacture includes a computer readable medium and computer-executable instructions carried on the computer readable medium. The instructions are readable by a processor. The instructions, when read and executed, cause the processor, for a network element communicatively coupled to another network element in a node portal located at the edge of an administrative network domain, to monitor a protect path for an APS message from a source network element, determine that the APS message has been received, monitor an intraportal link for an expected message from the other network element, determine that the expected message has not been received, monitor integrity of the intraportal link, determine that the intraportal link has failed, and determine that the other network element has failed based upon determining that that the APS message has been received, that the expected message has not been received, and that the intraportal link has failed. The APS message indicates a failure of a working path. The source network element is within a network attached to the node portal. The working path is between the other network element and the source network element.

In still yet another embodiment, an article of manufacture includes a computer readable medium and computer-executable instructions carried on the computer readable medium. The instructions are readable by a processor. The instructions, when read and executed, cause the processor to determine—at a node portal—failure in another node portal, and change a switch position of a selector function in the node portal in response to determining the failure in the other node portal. The node portal is communicatively coupled to the other node portal across an administrative network domain. Changing the switch position includes maintaining communication over a working path between the first node portal with a network element in a network attached to the first node portal.

In yet another embodiment, a system includes a network element communicatively coupled to another network element through an intraportal link forming a node portal. The network element is communicatively coupled to a source network element within a network attached to the node portal. The network element is configured to monitor a protect path for an APS message from the source network element, determine that the APS message has been received, monitor an intraportal link for an expected message from the other network element, determine that the expected message has not been received, monitor integrity of the intraportal link, determine that the intraportal link has failed and determine that the other network element has failed based upon determining that that the APS message has been received, that the expected message has not been received, and that the intraportal link has failed.

In still yet another embodiment, a system includes a node portal communicatively coupled to another node portal across an administrative network domain. The node portal is configured to determine a failure in another node portal and change a switch position of a selector function in the node portal in response to determining the failure in the other node portal. Changing the switch position includes maintaining communication over a working path between the first node portal with a network element in a network attached to the first node portal.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and its features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is an illustration of example embodiment of a system for providing node failure detection;

FIG. **2A** is an illustration of example operation of a system when using ring distributed linear protection;

FIG. **2B** illustrates example operation of a system to detect link failure when using ring distributed linear protection;

FIG. 2C illustrates example operation of a system to respond to detected link failure when using ring distributed linear protection;

FIG. 2D illustrates example operation of a system to detect node failure when using ring distributed linear protection;

FIG. 2E illustrates example operation of a system to respond to detected node failure when using ring distributed linear protection;

FIG. 3A is an illustration of example operation of a system when using mesh distributed linear protection;

FIG. 3B illustrates example operation of a system to detect link failure when using mesh distributed linear protection;

FIG. 3C illustrates example operation of a system to respond to detected link failure when using mesh distributed linear protection;

FIG. 3D illustrates example operation of a system to detect node failure when using mesh distributed linear protection;

FIG. 3E illustrates example operation of a system to respond to detected node failure when using mesh distributed linear protection; and

FIG. 4 illustrates an example embodiment of a method 400 for node failure detection.

DETAILED DESCRIPTION

FIG. 1 is an example embodiment of a system 100 for providing node failure detection. Such failure detection may be made in conjunction with providing linear protection for communication links in system 100. The linear protection may include distributed linear protection. For example, system 100 may utilize G.8031 Ethernet Linear Protection, G.873.1 Optical Transport Network (OTN) Linear Protection, Multiprotocol Label Switching Transport Profile (MPLS-TP) Linear Protection G.8131.1, or MPLS-TP Linear Protection G.8131.2 standards. System 100 may be configured to provide node failure detection such that various elements of system 100 may instantiate protection connections to maintain communication links. In one embodiment, system 100 may be configured to provide node failure detection when using mesh distributed linear protection. In another embodiment, system 100 may be configured to provide node protection when using ring distributed linear protection. In yet another embodiment, system 100 may be configured to provide node protection when using a hybrid between ring and mesh distributed linear protection.

System 100 may include any suitable number and kind of network elements (NE). For example, system 100 may include NE1 102, NE2 104, NE3 106, and NE4 108. NE1 102 and NE2 104 may be communicatively coupled. Furthermore, NE3 106 and NE4 108 may be communicatively coupled. In addition, NE1 and NE3 may be communicatively coupled and NE2 and NE4 may be communicatively coupled. Depending upon the communication model used to implement system 100, NE1 102 and NE4 108 may be communicatively coupled and NE2 104 and NE3 may be communicatively coupled.

NE1 102, NE2 104, NE3 106, and NE4 108 may be implemented in any suitable manner. For example, NE1 102, NE2 104, NE3 106, and NE4 108 may be implemented as a network switch, router, server, line card, or other suitable electronic or optical device. Each of NE1 102, NE2 104, NE3 106, and NE4 108 may include a processor 136, 140, 144, 148, respectively, communicatively coupled to a memory 138, 142, 146, 150, respectively. Processors 136, 140, 144, 148 may each comprise, for example, a microprocessor, microcontroller, digital signal processor (DSP), application specific integrated circuit (ASIC), or any other digital or analog circuitry configured to interpret and/or execute program instructions and/or process data. Processors 136, 140, 144, 148 may interpret and/or execute program instructions and/or process data stored in respective ones of memories 138, 142, 146, 150. Memories 138, 142, 146, 150 may comprise any system, device, or apparatus configured to hold and/or house one or more memory modules. Each memory module may include any system, device or apparatus configured to retain program instructions and/or data for a period of time (e.g., computer-readable media). The configuration and operation of NE1 102, NE2 104, NE3 106, and NE4 108 may be partially or fully implemented by instructions on memories 138, 142, 146, 150, respectively, when loaded and executed by processors 136, 140, 144, 148.

Each of NE1 102, NE2 104, NE3 106, and NE4 108 may further include a pair of selector and bridge (SB) devices. For example, NE1 102 may include SBs 120, 122; NE2 104 may include SBs 124, 126; NE3 106 may include SBs 128, 130; and NE4 108 may include SBs 132, 134. Each SB may include the ability to selectively route signals between two of its inputs. Each SB may be implemented in any suitable manner, such as by a switch controlled by the respective NE in which the SB resides. Each pair of SBs within the respective ones of NE1 102, NE2 104, NE3 106, and NE4 108 may be communicatively coupled to each other. Furthermore, the SBs within the respective ones of NE1 102, NE2 104, NE3 106, and NE4 108 may be communicatively coupled to two or more other elements of system 100. Thus, the communicative coupling between NEs 102, 104, 106, 108 may be determined by the configuration of their respective SBs. For example, SB 120 of NE1 102 may be communicatively coupled to SB 124 of NE2 and to a computing element (CE) 116; SB 122 of NE1 102 may be communicatively coupled to SB 126 of NE2 and to SB 128 of NE3; SB 124 of NE2 104 may be communicatively coupled to CE 116; SB 126 of NE2 104 may be communicatively coupled to SB 132 of NE4; SB 128 of NE3 106 may be communicatively coupled to SB 132 of NE4; SB 130 of NE3 106 may be communicatively coupled to SB 134 of NE4 108 and to a CE 118; and SB 134 of NE4 108 may be communicatively coupled to CE 118. Depending upon the communication model used to implement system 100, SB 122 of NE1 102 may be communicatively coupled to SB 132 of NE4 108 and SB 126 of NE2 104 may be communicatively coupled to SB 128 of NE3 106.

System 100 may be configured according to any suitable reference model. Such a reference model may be established according to the standard or protocol used in distributed linear protection. For example, in one embodiment, system 100 may be configured according to a Network to External Network-Network Interface (N2E) reference model. In such a model, NE1 102 and NE2 104 may form a first portal from which input/output is received/sent from network 110. NE3 106 and NE4 108 may form a second portal in which input/output is received/sent from network 114. NE1 106 may be communicatively coupled to NE4 108 through SBs 122, 132, and NE2 108 may be communicatively coupled to NE3 106 through SBs 126, 128. Furthermore, in such a model, a first domain 152 may be formed by the combination of network 110 and SBs 120, 124. Such a domain 152 may include a first OTN, Ethernet, or MPLS-TP protection domain. A domain 154 may be formed by the combination of SBs 122, 126, 128, 132. Such a domain 154 may include an External Network-Network Interface (E-NNI) protection domain configured for OTN or Ethernet. In addition, a domain **156** may be formed by the combination of network **114** and SBs **130**, **134**. Such a domain **156** may include a second OTN, Ethernet, or MPLS-TP protection domain. The portals formed by the combination of NE**1** **102** and NE**2** **104**, and by NE**3** **106** and NE**4** **108**, may form E-NNI portals.

Domains **152**, **154**, **156** may each implement an administrative network domain. Such an administrative network domain may be managed as a single, unitary network. Portals, such as those formed by a suitable combination of NE**1** **102**, NE**2** **104**, NE**3** **106**, and NE**4** **108**, may implement an ingress or egress into an administrative network domain such that an entity managing the network domain may control the transmission of information in or out of the network domain through control or management of the respective portal. Thus, a portal may be located at the logical edge of an administrative network domain.

In another example, system **100** may be configured according to a Network to User Network Interface (N2U) Reference Model. In such a model, NE**1** **102** and NE**2** **104** may form a first portal from which input/output is received/sent from CE **116** and received/sent from network **110**. NE**3** **106** and NE**4** **108** may form a second portal in which input/output is received/sent from network **114**. Furthermore, in such a model, a first domain **152** may be formed by the combination of CE **116** and SBs **120**, **124**. Such a domain **152** may include an Ethernet User Network Interface (UNI) protection domain. A UNI may be established between CE **116** and the pair of SBs **120**, **124**.

In yet another example, system **100** may be configured according to a Network to Network (N2N) Reference Model. In such a model, NE**1** **102** and NE**2** **104** may form a first portal from which input/output is received/sent from network **110**. NE**3** **106** and NE**4** **108** may form a second portal in which input/output is receive/sent from network **114**. Furthermore, in such a model, a first domain **152** may be formed by the combination of network **110** and SBs **120**, **124**, and a second domain **156** may be formed by the combination of network **114** and SBs **130**, **134**.

A domain **154** may be formed by the combination of SBs **122**, **126**, **128**, **132** and network **112**. Such a domain **154** may include an Ethernet, MPLS-TP, or OTN Network protection domain. An E-NNI may be established between SBs **130**, **134** and any up-network recipients, such as network **114** or CE **118**. The portal formed by the combination of NE**1** **102** and NE**2** **104** may include a UNI portal. The portal formed by the combination of NE**3** **106** and NE**4** **108** may form an E-NNI portal.

The portals formed by NE**1** **102** and NE**2** **104**, and by NE**3** **106** and NE**4** **108**, may be collocated within the same device or geographically dispersed and interconnected through a network. In order to communicatively couple portions of a single portal (such as, for example, NE**1** **102** and NE**2** **104**), the portal may include one or more intraportal links (IPL) **158**, **160**, **162**, **164**. Each of IPLs **158**, **160**, **162**, **164** may include a physical link and a logical link. IPLs **158**, **160**, **162**, **164** may be configured to carry data plane traffic, automatic protection switching (APS) messages, and other monitoring messages that a given one of NE**1** **102**, NE**2** **104**, NE**3** **106**, and NE**4** **108** may use to monitor the status of another one of NE**1** **102**, NE**2** **104**, NE**3** **106**, and NE**4** **108** within the same portal.

The utilization of IPLs **158**, **160**, **162**, **164** may depend upon the configuration of system **100**. For example, when using an N2E model in a ring configuration, IPL **158** may be active in domain **152** (which may be configured as a first protection domain); IPL **160** and IPL **162** may be active in domain **154** (which may be configured as an E-NNI domain); and IPL **164** may be active in domain **156** (which may be configured as a second protection domain). In another example, when using an N2E model in a mesh configuration, IPL **158** may not be active; IPL **160** and IPL **162** may be active in domain **154** (which may be configured as an E-NNI domain); and IPL **164** may be active in domain **156** (which may be configured as a second protection domain).

Networks **110**, **112**, **114** may each comprise any suitable network—for example, a local-area-network, wide-area-network, a network of metro Ethernet switches, virtual-local-area-network, optical networks, Ethernet networks, an intranet, or a portion of the Internet. Networks **110**, **112**, **114** may include elements configured for UNI, E-NNI, or both. Furthermore, networks **110**, **112**, **114** may include elements be configured to utilize singled-homed or multiple-homed UNI. In such cases wherein multiple-homed UNI, such as double-homed UNI, is used, a customer node may be implemented by CE **116** or CE **118** and may be configured to connect to system **100** to provide UNI edge nodes.

CE **116**, **118** may include any suitable entity, such as a server, computer, router, or switch. CE **116**, **118** may include an entity within networks **110**, **114**, respectively. CE **116**, **118** may reside in any suitable portion of networks **110**, **114**, respectively, including at a service edge of such networks.

Entities within system **100** may communicate using linear protected switching and associated linearly protected switching connections. Such connections may include those protected using, for example, the G.8031, G.873.1, G.8131.1, or G.8131.2 standards. Furthermore, such connections may include a working path and a protect path. One of such paths may be designated as active, wherein an NE monitoring the paths for inbound traffic will accept packets from the active path and simply drop data packets from the other path, but still accept control packets required for the operation of a path protection protocol. In one embodiment, the working path may be initially configured as the active path. If the working path is down or otherwise unavailable, then the protect path may be configured as the active path. Each of SBs **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134** may be configured to provide routing of information through an active path. System **100** may be configured to determine whether various nodes or links of system **100** are down or inoperable, causing a reconfiguration of active paths, working paths, or protect paths. To affect such reconfiguration, each of NEs **102**, **104**, **106**, **108** may monitor respective protect paths for control and status messages, such as automatic protection switching ("APS") messages. APS messages may implement a control packet, include protocol messages, include property and state information of an originating switch, and may be exchanged using the protect path.

Each of NE**1** **102**, NE**2** **104**, NE**3** **106**, and NE**4** **108** may be configured to store pre-determined states of operation in memories **138**, **142**, **146**, **150**, respectively. Such states may be stored in any suitable manner, such as in a table, record, or other data structure. Each such table may contain indications, for each state, of what actions should be taken given any number of conditions observed.

NE**1** **102**, NE**2** **104**, NE**3** **106**, NE**4** **108**, CE **116**, and CE **118** may be configured to periodically exchange APS messages. Such messages may be exchanged one-for-one, and in both directions. Such APS messages may contain information pertaining to the status, state, and operation of a switch to be communicated to another switch. In addition, NE1 **102**, NE2 **104**, NE3 **106**, NE4 **108**, CE **116**, and CE **118** may be configured to periodically exchange "Keep-Alive Messages." Such a keep-alive message may be implemented in any suitable manner by which one entity sends a periodic or expected message to another entity to inform the other entity that the original entity is still functional and operating.

System **100** may utilize one-to-one linear protection. In such a case, user traffic may be transmitted on either of the protect path and working path. However, user traffic may not be transmitted on both the working path and protect path. If an entity attempts to transmit user traffic on working and another entity attempts to transmit user traffic on a corresponding protect path, neither entity will receive the other end's traffic, and the traffic may be lost.

Upon detection of a loss in user traffic, NE1 **102**, NE2 **104**, NE3 **106**, NE4 **108**, CE **116**, and CE **118** may be configured to switch to a different pre-determined state of operation based upon the conditions encountered. Such a state of operation may include directives that the switch move user traffic to from working path to a protect path, or vice-versa.

In the example of FIG. **1**, NE2 **104** may be configured to determine whether NE1 **102**, or a link associated with NE1 **102**, has failed. Similarly, NE1 **102** may be configured to determine whether NE2 **104**, or a link associated with NE2 **104**, has failed. Furthermore, NE3 **106** may be configured to determine whether NE4 **108**, or a link associated with NE4 **108**, has failed. Similarly, NE4 **108** may be configured to determine whether NE3 **106**, or a link associated with NE3 **106**, has failed. If any such failure associated with NE1 **102**, NE2 **104**, NE3 **106**, or NE4 **108** is determined, two or more of the other NEs of NE1 **102**, NE2 **104**, NE3 **106**, and NE4 **108** may be configured to communicate to perform reconfiguration of network communication links.

In one embodiment, system **100** may be utilized for ring distributed linear protection. FIG. **2**A is an illustration of example operation of system **100** when using ring distributed linear protection. In the example of FIG. **2**A, NE1 **102** and NE2 **104** may form a portal for network **110** through which CE **116** communicates. CE **116** may be configured with a UNI. NE1 **102** and NE3 **106** may form an E-NNI. Furthermore, NE2 **104** and NE4 **108** may form an E-NNI. NE3 **106** and NE4 **108** may form a second portal such that CE **118** may communicate through network **114**. A path **206** formed through network **110** may connect CE **116** and SB **120** of NE1 **102**, and a path **202** formed through network **110** may connect CE **116** and SB **124** of NE2 **104**. A path **204** may be formed connecting SB **120** of NE1 **102** and SB **124** of NE2 **104**. Path **204** may be implemented by, for example, IPL **158**. IPLs **158**, **160**, **162**, **164** may be active.

In the example of FIG. **2**A, during normal operation a working path may be established between CE **116** and the first portal formed by NE1 **102** and NE2 **104**. Furthermore, during normal operation a protect path may be established between CE **116** and the first portal formed by NE1 **102** and NE2 **104**. For example, path **206** may be initially designated as the working path and path **202** may be initially designated as the protect path. Additionally, path **204** may be designated as a protect path. Other working and protect paths may be established within system **100**, such as between SB **130**, SB **134**, and CE **118**.

Each working path and protect path may be independently monitored by a part of maintenance association end points (MEP). The designation of what portions of system **100** are implemented as MEPs may be determined according to the protocols or standards used by system **100**. For example, when using OTN, MEPs may include Optical Data Unit k path (ODUkP) termination points. Such ODUkP termination points may include a high-order or low-order ODUk in a given segment using protect and working paths. In such an example, Trail Trace may be used to determine whether an element is functioning correctly in a keep-alive message. In another example, when using Ethernet, MEPs may include Service Operations, Administration, and Maintenance (SOAM) Connectivity Fault Management (CFM) MEPs. These SOAM CFM MEPs may utilize monitoring of Continuity Check Messages (CCM). In yet another example, when using MPLS-TP, MEPs may include specific CFM monitoring endpoints based upon, for example, SOAM CFM (according to the International Telecommunication Union (ITU) 8113.1 specification) or Internet Engineering Task Force (IETF)-defined Bidirectional Forwarding Detection (BFD) (according to the ITU 8113.2 specification). Such endpoints may utilize keep-alive monitoring.

Each of SBs **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134** are illustrated with at least three connector points. Each connector point may be communicatively coupled to a node external to the respective SB. Given instructions, commands, or control by their respective NEs, each of SBs **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134** may be configured to selectively route input and output by connecting two of the three connector points.

FIG. **2**B illustrates example operation of system **100** to detect link failure when using ring distributed linear protection. When path **206** (the working path) fails at **208**, CE **116** and NE1 **102** may each independently detect the failure. Each may generate an APS message detailing such a determination and send it to NE2 **104** along respective paths **202**, **204**. Thus, NE2 **104** receives, independently, APS messages on protect path (path **202**) and an IPL (path **204**).

Because NE2 **104** receives messages indicating failure from both NE1 **102** and CE **116**, NE2 **104** may determine that the path **206** has failed yet NE1 **102** has not failed. NE2 **104** may determine that the error has occurred somewhere in network **110**, rather than internally to NE1 **102**.

FIG. **2**C illustrates example operation of system **100** to respond to detected link failure when using ring distributed linear protection. System **100** may perform any suitable number or combination of selector changes within various SBs **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134**. For example, NE2 **104** may make a selector change in SB **124** to connect path **202** and path **204**. Such a change may connect two protect paths. Furthermore, such a change may connect a protect path to CE **116** to the IPL for SB **120** of NE1 **102** within the same portal.

In one embodiment, NE2 **104** may respond with an APS message to each endpoint—one in NE1 **102** and one in CE **116**. In another embodiment, NE2 **104** may allow APS messages to directly flow between NE1 **102** and CE **116**. In such an embodiment, NE2 **104** may perform any necessary APS translation.

CE **116** and NE1 **102** may switch to the protect path built upon paths **202** and **204**. The working path may then be designated as paths **202** and **204**.

FIG. **2**D illustrates example operation of system **100** to detect node failure when using ring distributed linear protection. Recovery from such node failure may be based upon a portal node detecting failure of another node from within the same portal. In one embodiment, system **100** may utilize triangulation to determine node failure.

In the example of FIG. **2**D, NE1 **102** may fail **210**. NE2 **104** may detect a resulting APS request from CE **116** over path **202**. Furthermore, NE2 **104** may fail to receive a message from NE1 **102** over path **204**. Such a message may be expected if NE1 **102** is operating correctly. The message may include, for example, an APS message or keep-alive messages. In addition, NE2 **104** may detect a loss of its IPL itself, represented by path **204**. NE2 **104** may determine, based on the loss of APS messages from NE1 **102** or other keep-alive messages, the loss of IPL on path **204**, and the APS messages received from CE **116**, that NE1 **102** has failed.

FIG. **2**E illustrates example operation of system **100** to respond to detected node failure when using ring distributed linear protection.

NE2 **104** may honor the APS request from CE **116**. System **100** may perform any suitable number and combination of selector changes. For example, NE2 **104** may make a selector change, if necessary, in SB **124** to route path **202** to SB **126**, and, if necessary, in SB **126** to route its input from SB **124** to NE4 **108**. NE2 may activate the protect path on path **202** such that path **202** may now include the working path.

Other elements of domain **154** (configured as an E-NNI domain) may independently also detect failure of NE1 **102** and provide similar switching of paths and selector changes within respective SBs. Each of the other elements, such as NE3 **106** and NE4 **108**, may make such determinations in any suitable manner. For example, such other elements may make such determinations in similar fashion as NE2 **104**. In another example, NE4 **108** may make such a determination upon receiving new input or APS messages from CE **116** or NE2 **104**. NE3 **106** may make such a determination upon failing to receive input from NE1 **102** and upon receiving new input or APS messages from NE4 **108**. Upon determining failure of NE1 **102**, NE4 **108** may make a selector change, if necessary, in SB **132** to route its input from SB **126** of NE2 **104** to SB **128** of NE3 **106**. Such routing may thus include routing over the IPL **162** between NE3 **106** and NE4 **108**. NE3 **106** may make a selector change, if necessary, in SB **128** to route its input from SB **132** of NE4 **108** to SB **130** and on to CE **118**. Thus, the protection domain of domain **156** in network **114** may require no changes.

FIG. **3**A is an illustration of example operation of system **100** when using mesh distributed linear protection. In the example of FIG. **3**A, NE1 **102** and NE2 **104** may form a portal for network **110** through which CE **116** communicates. CE **116** may be configured with a UNI. NE1 **102** and NE3 **106** may form an E-NNI. Furthermore, NE2 **104** and NE4 **108** may form an E-NNI. NE3 **106** and NE4 **108** may form a second portal such that CE **118** may communicate through network **114**. Two paths **304**, **306** formed through network **110** may connect CE **116** and SB **120** of NE1 **102**. A path **302** formed through network **110** may connect CE **116** and SB **124** of NE2 **104**. An IPL between SB **120** of NE1 **102** and SB **124** of NE2 **104** may be absent or inactive. IPLs **160**, **162** may be active.

In the example of FIG. **3**A, during normal operation a working path may be established between CE **116** and the first portal formed by NE1 **102** and NE2 **104** along path **304**. Furthermore, during normal operation protect paths may be established between CE **116** and the first portal formed by NE1 **102** and NE2 **104** along paths **306** and **302**.

Thus, path **304** may be initially designated as the working path and paths **302**, **306** may be initially designated as the protect path. Other working and protect paths may be established within system **100**, such as between SB **130**, SB **134**, and CE **118**.

FIG. **3**B illustrates example operation of system **100** to detect link failure when using mesh distributed linear protection. When path **304** (the working path) fails at **308**, CE **116** and NE1 **102** may each independently detect the failure. Each may generate an APS message detailing such a determination and send it to each other along path **306**.

FIG. **3**C illustrates example operation of system **100** to respond to detected link failure when using mesh distributed linear protection. System **100** may perform any suitable number or combination of selector changes within various SBs **120**, **122**, **124**, **126**, **128**, **130**, **132**, **134**. For example, NE1 **102** may make a selector change in SB **120** to connect path **306** to SB **122** and the remainder of the previously existing path. The working path may then be designated as paths **306**.

FIG. **3**D illustrates example operation of system **100** to detect node failure when using mesh distributed linear protection. Recovery from such node failure may be based upon a portal node detecting failure of another node from within the same portal. In one embodiment, system **100** may utilize triangulation to determine node failure. NE1 **102** may be shared by both networks **110**, **112**.

In the example of FIG. **3**D, NE1 **102** may fail **310**. CE **116** may detect the failure of both path **304** (including the working path) and path **306** (another protect path). CE **116** may send an APS message to NE2 **104** on path **302** (the first protect path). NE2 **104** may detect a resulting APS request from CE **116** over path **302**. Furthermore, NE2 **104** may fail to receive a message from NE1 **102** over IPL **160**. Such a message may be expected to be received if NE1 **102** is operating normally. The message may include, for example, an APS message or a keep-alive message. In addition, NE2 **104** may detect a loss of IPL **160**.

NE2 **104** may determine, based on the loss of APS messages from NE1 **102** or other keep-alive messages, the loss of IPL **160**, and the APS messages received from CE **116**, that NE1 **102** has failed.

FIG. **3**E illustrates example operation of system **100** to respond to detected node failure when using ring distributed linear protection. NE2 **104** may NE2 **104** may honor the APS request from CE **116**. System **100** may perform any suitable number and combination of selector changes. For example, NE2 **104** may make a selector change, if necessary, in SB **124** to route path **302** to SB **126**, and, if necessary, in SB **126** to route its input from SB **124** to NE4 **108**. NE2 may activate the protect path on path **302** such that path **302** may now include the working path.

Other elements of domain **154** (configured as an E-NNI domain) may independently also detect failure of NE1 **102** and provide similar switching of paths and selector changes within respective SBs. Each of the other elements, such as NE3 **106** and NE4 **108**, may make such determinations in any suitable manner. For example, such other elements may make such determinations in similar fashion as NE2 **104**. In another example, NE4 **108** may make such a determination upon receiving new input or APS messages from CE **116** or NE2 **104**. NE3 **106** may make such a determination upon failing to receive input from NE1 **102** and upon receiving new input or APS messages from NE4 **108**. Upon determining failure of NE1 **102**, NE4 **108** may make a selector change, if necessary, in SB **132** to route its input from SB **126** of NE2 **104** to SB **128** of NE3 **106**. Such routing may thus include routing over the IPL **162** between NE3 **106** and NE4 **108**. NE3 **106** may make a selector change, if necessary, in SB **128** to route its input from SB **132** of NE4 **108** to SB **130** and on to CE **118**. Thus, the protection domain of domain **156** in network **114** may require no changes.

The operation of NE1 **102**, NE2 **104**, NE3 **106**, or NE4 **108** to detect and respond to node failure in system **100** may be established by configuring various pre-determined states of operation, depending upon the conditions encountered. Pre-determined states of operation may indicate any suitable information about operational settings or conditions encountered. For example, pre-determined states of operation may indicate to NE**1** **102**, NE**2** **104**, NE**3** **106**, or NE**4** **108** which paths should be used for working path or protect path communication given the occurrence of a particular event.

FIG. **4** illustrates an example embodiment of a method **400** for node failure detection. In **405**, at a NE within a system, a protect path and an IPL may be established. The protect path may be established between the NE and a networked entity. The IPL may be established with another NE. The NE and the other NE may form a portal of nodes by which the networked entity is provided linear protection. The network may utilize linear protection, such as Ethernet G.8031, OTN G.873.1, and MPLS-TP G.8131.1 and G.8131.2. Furthermore, the network may be configured according to mesh, ring, or hybrid mesh-ring topology. Using such a hybrid mesh-ring topology, the protection capacity of some ring links may be oversubscribed, such that a given ring link may protect working paths with greater capacity than itself. In addition, then network may be configured according to N2U, N2E, or N2N models.

At **410**, the protect path may be monitored for APS messages indicating a working path failure from the networked entity. At **415**, the IPL may be monitored for messages from the other NE of the portal. Such messages may be expected to be received if the NE is operating normally and may include, for example, APS messages or keep-alive messages. At **420**, the IPL may be monitored for the integrity of the IPL itself.

At **425**, it may be determined whether an APS message indicating a working path failure from the networked entity has been received. If not, method **400** may return to **410**. If so, at **430**, it may be determined whether any messages have been received from the other NE of the portal. Such messages may be expected to be received if the other NE of the portal is operating properly. The messages may include, for example, APS or keep-alive messages. If any messages have been received, method **400** may return to **410** or take corrective action with regards to the working path failure. If such messages have not been received, at **435** it may be determined whether the IPL path is active. If so, method **400** may return to **410** or take corrective action with regards to the working path failure or missing APS or keep-alive messages. If so, at **440** it may be determined that the other NE of the portal has failed. Any suitable corrective action may be taken.

For example, at **445**, routing configuration of the NE may be changed so as to route the protect path to another node portal. Such routing may, for example, shift the protect path from away from IPL connecting the NE and the failed NE. At **450**, other NEs of the system may adjust routing so as to accept the newly rerouted protect path and route it to the original intended destination. Such other NEs may include, for example, NEs of the other node portal. At **455**, the rerouted protect path may be designated as the working path. At **460**, an APS message may be sent to the networked entity informing the networked entity about the determined failure or the rerouting. The method may terminate.

The steps of method **400** may be conducted in parallel by different entities implementing method **400**. Furthermore, method **400** may be conducted in parallel with other methods for providing linear protection. Although FIG. **4** discloses a particular number of steps to be taken with respect to an example method **400**, method **400** may be executed with more or fewer steps than those depicted in FIG. **4**. In addition, although FIG. **4** discloses a certain order of steps to be taken with respect to method **400**, the steps comprising method **400** may be completed in any suitable order. Method **400** may be implemented using the system of FIGS. **1-3** or any other system, network, or device operable to implement method **400**. In certain embodiments, method **400** may be implemented partially or fully in software embodied in computer-readable media.

For the purposes of this disclosure, computer-readable media may include any instrumentality or aggregation of instrumentalities that may retain data and/or instructions for a period of time. Computer-readable media may include, without limitation, storage media such as a direct access storage device (e.g., a hard disk drive or floppy disk), a sequential access storage device (e.g., a tape disk drive), compact disk, CD-ROM, DVD, random access memory (RAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), and/or flash memory; as well as communications media such wires, optical fibers, and other electromagnetic and/or optical carriers; and/or any combination of the foregoing.

Although the present disclosure has been described in detail, it should be understood that various changes, substitutions, and alterations can be made hereto without departing from the spirit and the scope of the disclosure as defined by the appended claims

What is claimed is:

1. A method for linear protection, comprising, for a first network element communicatively coupled to a second network element, the first network element and the second network element included in a first node portal located at the edge of a first administrative network domain:

monitoring, by the first network element, a protection path for an automatic protection switching ("APS") message from a third network element included within a network attached to the first node portal, the APS message indicating a failure of a working path between the second network element and the third network element;

determining, by the first network element, that the APS message has been received;

monitoring, by the first network element, an intraportal link for a message from the second network element;

determining, by the first network element, that the message from the second network element has not been received;

monitoring, by the first network element, integrity of the intraportal link;

determining, by the first network element, that the intraportal link has failed;

determining, by the first network element, that the second network element has failed based upon determining that that the APS message has been received, that the message from the second network element has not been received, and that the intraportal link has failed;

activating the protection path; and

transmitting data between the third network element and a node within a second node portal communicatively coupled to the first node portal and located across a second administrative network domain, the transmitting data bypassing the second network element.

2. The method of claim **1**, further comprising activating the protection path by changing a switch position of a selector function of the first network element.

3. The method of claim **1**, further comprising sending an APS message to the third network element based upon the determination that the second network element has failed.

4. The method of claim 1, further comprising designating the protection path as a working path after a protection switching event.

5. The method of claim 1, wherein the first network element is configured to communicate using G.8031 Ethernet Linear Protection, G.873.1 Optical Transport Network Linear Protection, or Multiprotocol Label Switching Transport Profile Linear Protection G.8131.1 and G.8131.2 standards.

6. The method of claim 1, wherein the first network element is configured to provide linear protection as part of a mesh network model, ring network model, or hybrid mesh-ring network model.

7. The method of claim 1, wherein the first network element is configured to provide linear protection in conjunction with a single-homed or dual-homed user network interface (UNI).

8. The method of claim 1, wherein the first network element is configured to provide linear protection as part of a Network-to-UNI model, Network-to-Ethernet-Network-Interface model, or Network-to-Network model.

9. An article of manufacture comprising:
- a computer readable medium; and
- computer-executable instructions carried on the computer readable medium, the instructions readable by a processor, the instructions, when read and executed, for causing the processor to, for a first network element communicatively coupled to a second network element, the first network element and the second network element included in a first node portal located at the edge of a first administrative network domain:
  - monitor, by the first network element, a protection path for an automatic protection switching ("APS") message from a third network element included within a network attached to the first node portal, the APS message indicating a failure of a working path between the second network element and the third network element;
  - determine, by the first network element, that the APS message has been received;
  - monitor, by the first network element, an intraportal link for a message from the second network element;
  - determine, by the first network element, that the message from the second network element has not been received;
  - monitor, by the first network element, integrity of the intraportal link;
  - determine, by the first network element, that the intraportal link has failed;
  - determine, by the first network element, that the second network element has failed based upon determining that that the APS message has been received, that the message from the second network element has not been received, and that the intraportal link has failed;
  - activate the protection path; and
  - transmit data between the third network element and a node within a second node portal communicatively coupled to the first node portal and located across a second administrative network domain, the transmitting data by passing the second network element.

10. The article of claim 9, further comprising instructions for causing the processor to
- change the routing of the first network element to route the protection path to a second node portal based on the determination that the second network element has failed.

11. The article of claim 9, further comprising instructions for causing the processor to activate the protection path by changing a switch position of a selector function of the first network element.

12. The article of claim 9, further comprising instructions for causing the processor to send an APS message to the third networked element based upon the determination that the second network element has failed.

13. The article of claim 9, further comprising instructions for causing the processor to designate the protection path as a working path after a protection switching event.

14. The article of claim 9, wherein the first network element is configured to communicate using G.8031 Ethernet Linear Protection, G.873.1 Optical Transport Network Linear Protection, or Multiprotocol Label Switching Transport Profile Linear Protection G.8131.1 and G.8131.2 standards.

15. The article of claim 9, wherein the first network element is configured to provide linear protection as part of a mesh network model, ring network model, or hybrid mesh-ring network model.

16. The article of claim 9, wherein the first network element is configured to provide linear protection in conjunction with a single-homed or dual-homed user network interface (UNI).

17. The article of claim 9, wherein the first network element is configured to provide linear protection as part of a Network-to-UNI model, Network-to-Ethernet-Network-Interface model, or Network-to-Network model.

18. A system comprising:
- a first network element; and
- a second network element communicatively coupled to the first network element through an intraportal link forming a first node portal;
- wherein the first network element is communicatively coupled to a third network element within a network attached to the first node portal and the first network element is configured to:
  - monitor a protection path for an automatic protection switching ("APS") message from the third network element, the APS message indicating a failure of a working path between the second network element and the third network element;
  - determine that the APS message has been received;
  - monitor the intraportal link for a message from the second network element;
  - determine that the message from the second network element has not been received;
  - monitor integrity of the intraportal link;
  - determine that the intraportal link has failed;
  - determine that the second network element has failed based upon determining that that the APS message has been received, that the message from the second network element has not been received, and that the intraportal link has failed;
  - activate the protection path; and
  - transmit data between the third network element and a node within a second node portal communicatively coupled to the first node portal and located across a second administrative network domain, the transmitting data bypassing the second network element.

19. The system of claim 18, wherein the first network element is further configured to
- change the routing of the first network element to route the protection path to a second node portal based on the determination that the second network element has failed.

20. The system of claim **18**, wherein the first network element is further configured to activate the protection path by changing a switch position of a selector function of the first network element.

21. The system of claim **18**, wherein the first network element is further configured to send an APS message to the third networked element based upon the determination that the second network element has failed.

22. The system of claim **18**, wherein the first network element is further configured to designate the protection path as a working path after a protection switching event.

23. The system of claim **18**, wherein the first network element is configured to communicate using G.8031 Ethernet Linear Protection, G.873.1 Optical Transport Network Linear Protection, or Multiprotocol Label Switching Transport Profile Linear Protection G.8131.1 and G.8131.2 standards.

24. The system of claim **18**, wherein the first network element is configured to provide linear protection as part of a mesh network model, ring network model, or hybrid mesh-ring network model.

25. The system of claim **18**, wherein the first network element is configured to provide linear protection in conjunction with a single-homed or dual-homed user network interface (UNI).

26. The system of claim **18**, wherein the first network element is configured to provide linear protection as part of a Network-to-UNI model, Network-to-Ethernet-Network-Interface model, or Network-to-Network model.

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